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(54) COMPUTER ASSISTED RADIATION THERAPY MACHINE

(71) We, VARIAN ASSOCIATES of 611 Hansen Way, Palo Alto, California, United States of America, a corporation organized under the laws of the State of California, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to a radiation therapy apparatus comprising couch means for supporting a patient to receive radiation, and radiation source means for applying radiation to the patient.

Heretofore, the mechanical setup of a radiation therapy machine has been automated for decreasing the setup time and improving the accuracy of the mechanical setup for a radiation therapy treatment. In the prior machine, the desired positional information for the mechanical setup of the machine was punched into cards according to a prescribed plan of treatment. A deck of cards representing the setup for the prescribed plan of treatment was fed into a card reader. The output of the card reader was fed to control circuits for sequentially controlling the mechanical motions of various movable parts of the machine for geometrically positioning the gantry and treatment couch according to the prescribed plan of treatment. The cards were read sequentially. A four digit visual display was provided for displaying the position of each of the mechanically movable elements of the radiation therapy machine.

While the aforecited automated radiation therapy machine substantially decreased the setup time and improved the accuracy of the setup, it still leaves room for operator error or machine error, as the operator must compare the readout positions of the various movable elements against a treatment plan to see that each of the elements is in the desired position. In addition, the operator must set the treatment time for the radiation dose according to the treatment plan, thereby introducing further chance of error. The prior art machine did not include means for automatically maintaining an updated reading of cumulative radiation dose delivered to a patient through a prescribed radiation portal nor did it automatically maintain a cumulative total of radiation administered to a given patient. The prescribed treatment plan for a patient, in the prior machine, could be edited and updated by punching a new set of punched cards. However, mistakes could be made by the keypunch operator and these mistakes would be incorporated into the treatment plan to be administered to the patient.

It is an object of the present invention to provide an improved automated radiation therapy machine.

According to the present invention, there is provided a radiation therapy apparatus comprising couch means for supporting a patient to receive radiation, radiation source means for applying radiation to the patient, means for supporting and moving said radiation source means around said couch means, means for storing information defining geometric and radiation dose parameters of the radiation machine for defining a prescribed radiation treatment to be administered to the patient, means for reading out of said storage means and displaying to an operator the geometric and dose parameters defining the prescribed plan of radiation treatment, means for deriving an output representative of the dose of radiation actually administered to the patient from said source means in carrying out the defined plan of treatment, means for editing and updating said storage means with the derived dose output by adding the derived dose output to the cumulative total of previously derived dose outputs, if any, administered to the certain patient and stored in said storage means, to obtain an updated cumulative total radiation dose output in said storage means.

One feature of the present invention is the provision of means for automatically editing and updating a patient's treatment plan with the cumulative total of radiation dose, if any, administered to the certain patient.

Another feature of the present invention is the same as the preceding feature wherein the means for automatically editing and updating the patient's treatment plan includes a programmed general purpose computer.

In another feature of the present invention, cathode ray tube keyboard terminal or a teletype terminal is interactively coupled to a general purpose computer for editing, reading out, and displaying the updated treatment plan.

In another feature of the present invention, information defining a radiation treatment plan for a given patient is stored in a first memory means, such as magnetic tape cassette paper tape or magnetic disc. This information is transferred into the memory of the computer and the computer reads the stored information, upon command, to a read-out and display terminal having the capability for updating the treatment plan information stored in the computer.

In another feature of the present invention information is stored defining permissible ranges of values for a treatment plan of machine parameters and the corresponding parameters of a proposed treatment plan are compared against the stored range of permissible value to derive an interlock output if the value of a proposed machine parameter is outside the range of permissible values. The interlock output is employed to prevent transfer of the proposed treatment parameter into the treatment plan for the patient.

Another feature of the present invention is the provision of means for automatically checking the setup of the radiation machine against a prescribed plan of treatment and noting any discrepancies therebetween and initiating an interlock output which inhibits application of radiation to the patient until the discrepancy between the treatment plan and the actual settings of the machine have been eliminated, whereby treatment mistakes are minimized.

Another feature of the present invention is the same as the preceding feature wherein the means for automatically comparing the treatment plan against the actual settings of the machine comprises a programmed general purpose computer.

In another feature of the present invention, display means are provided for displaying to the operator the prescribed treatment plan and the actual settings of the radiation machine such that the operator is readily apprised of any discrepancies therebetween.

In another feature of the present invention, the prescribed settings for the radiation therapy machine are recorded on storage means, such as magnetic tape, disc or paper tape, and the machine includes means for reading the prescribed settings of the machine from the storage.

A radiation therapy apparatus in accordance with the invention will now be described, by way of example, with reference to the accompanying drawings, in which:—

Fig. 1 is a schematic diagram, partly in block diagram form, of an automated radiation therapy machine incorporating features of the present invention.

Fig. 2 is a schematic circuit diagram for deriving signals determinative of the settings of the respective variable parameters of the radiation therapy machine,

Fig. 3 is a program flow chart for a computer which controls the setup and avoids collision between the gantry and couch portions of the radiation therapy machine of the present invention,

Fig. 4 is a view similar to that portion of Fig. 1 delineated by line 4—4 showing dimensions, and

Fig. 5 is a sectional view of the structure of Fig. 4 taken along line 5—5 in the direction of the arrows.

Referring now to Fig. 1, there is shown a computer controlled radiation therapy machine incorporating features of the present invention. The radiation machine 1, such as a CLINAC[R] radiation therapy machine model 4 or 35, commercially available from Varian Associates ("Varian is a Registered Trade Mark), or a THERATRON 80 automated cobalt 60 radiation machine made by Atomic Energy of Canada Limited of Ottowa, Canada, includes a couch 2 having a table portion 3 which receives the patient to be treated. The couch 2 is rotatable about a vertical axis 4 by means of a turntable 5 to which the couch 2 is affixed. The couch includes an elevator portion 6 for translating the couch in the vertical direction Z. In addition, the couch includes motorized drives for translating the table 3 in the lateral Y direction and longitudinal X direction. A control pendant 10 is connected to the couch 2 via suitable cable for manual control of the various portions of the radiation machine 1 and for allowing automatic control of the radiation machine 1 by the computer.

A generally C-shaped gantry 8 is rotatable by 359° about a horizontal axis 9. The gantry 8 is rotatably supported from a stand 11. A source of radiation, such as a linear accelerator producing a high energy electron beam which is directed against an X-ray target, produces a beam of X-rays emanating from a collimator head portion 12. As an alternative, in the case of the cobalt machine, the cobalt serves as a source of X-ray radiation, and is housed within the collimator head portion 12. The X-rays are directed out of the radiating head portion 12 in a beam having an axis 13 which intersects the gantry axis of rotation 9 at a position identified as the isocenter 14, which is also intersected by the turntable axis 4.

The head portion 12 includes two sets of

movable beam defining jaws, as of lead, which are movable to define the length L and thickness T of the field of the X-ray beam as collimated by the beam defining jaws. The source 12 is enclosed in a barrel shaped collimator housing 15. The source housing 15, along with beam defining jaws, are rotatable about the beam axis 13. The gantry 8 includes a beam stopping portion 16 disposed along the X-ray beam axis 13 and holding an X-ray absorbing material, such as lead, for stopping and absorbing the X-ray beam.

A digital computer 18, such as a Varian Data Machine Model 620/i general purpose digital computer, is coupled to the radiation therapy machine 1 via the intermediary of a control cable 19 and an interface 21. The computer 18 includes a core memory portion 22 interconnected to a central processor 23 which includes the address and arithmetic units. Sixteen channels of analog-to-digital converters 24 are provided for converting analog output signals derived from the radiation therapy machine 1 to digital form which are in-turn fed into the central processor 23 for use therein and for use in the memory 22. Eight channels of digital-to-analog converters 25 are provided for converting digital output signals from the central processor 23 into analog signals which in-turn are fed into the radiation therapy machine 1 via the intermediary of the interface 21. Sensor and control lines 26 are provided for sensing and controlling functions of the radiation therapy machine va the interface 21. A machine console 27 is coupled to the radiation therapy machine 1 and to the computer 18 via the machine interface 21.

The Varian data machines 620/i computer 18 is a system oriented digital computer. It has a total memory capacity of 12,388 words of sixteen or eighteen bits and is plug-in expandable. The memory is magnetic core with 1.8 microseconds full cycle and 700 nanoseconds access time. The arithmetic is parallel, binary, fixed points, 2's complement. It has seven addressing modes and over one hundred standard instructions. In addition, to the standard equipment which comes with the Varian 620/i computer, the computer 18 includes, a 620/i expansion chassis, two 620/i memory modules providing an extra 8,192 words, a 620/i-17 optional package, a 620/i-51 paper tape reader, an acquisition and control unit, and the 620/i machine interface 21.

The 620/i-17 optional package contains hardware multiply/divide extended addressing, real time clock, power fail/restart, and eight level priority interrupts. The 620/i-51 accessory is a high speed paper tape reader which provides for rapid means to load the memory should a program be lost or scrambled for some reason. It is an input device only and will not punch. It reads at 300 characters per second. The acquisition and control unit contains the following: 16 channels of multiplexed analog-to-digital conversion programmable for 7 or 12 bits plus sign, sample and hold amplifier (as indicated by reference numeral 24); and 8 digital-to-analog converters, each 9 bits plus sign (as indicated by reference number 25); plus sixteen sense lines and 8 control lines (as indicated by reference number 26). In addition, the acquisition and control unit contains the BCD registers and the controller for the BCD information available from the radiation machine console 27. The BCD information, i.e., the parameters monitored through the BCD input registers; includes: (1) wedge or block number, (2) time switch setting, (3) time reading; (4) integrated dose setting, (5) integrated dose reading, and (6) gantry stop angle setting.

A digital cassette tape unit 28, such as a model 100 COMPUCORDER available from Datatronics, Inc. of Rochester, New York, is coupled by suitable cables to the central processor 23 for reading digital data, stored in the patient's individual cassette, into the central processor 23 and memory 22. In addition, outputs from the processor 23 are recorded back into the patient's cassette via the tape unit 28. A cathode ray tube/keyboard terminal 29, such as a model ALPHA 103A CRT/keyboard terminal, commercially available from Beehive Medical Electronics, Inc. of Salt Lake City, is coupled to the central processor 23 via cable 31 for displaying data read from the memory 22 through the central processor 23 and for controlling certain operations of the radiation therapy machine 1 via the computer 18.

The CRT terminal 29 forms the major input-output device for the computer 18 and includes an alpha numeric display. It has a standard typewriter keyboard and four-way cursor control. In addition, it has an 11" CRT screen with 20 lines and 40 characters per line. The CRT terminal 29 has typeover capability using the cursor as well as line-erase and screen-clear. It has its own internal character generator with 64 characters ASC II set. A remote slave cathode ray tube (CRT) 32 is provided for remote data observation. A standard ASR 33 teletype unit is coupled to the central processor 23 via suitable cables to provide a hard copy printout and to serve as a backup input for the CRT/keyboard terminal 29 and for the paper tape reader accessory of the computer 18.

Referring now to Fig. 2 there is shown one of the circuits for generating an analog positional signal determinative of the position of one of the variable parameters of the radiation machine 1, such as: gantry angle G; housing angle, H; couch position in the X, Y and Z directions, etc. The positional signal circuit of Fig. 2 includes a potentiometer

34, as of 10 k ohms, attached to the drive shaft 35 via mechanical coupling 36. Drive shaft 34 generates the motion of the parameter being controlled, such that a full-scale motion of the parameter being varied or controlled results in generating a full scale +10 volts to −10 volts analog output derived from the pickoff 37 of the potentiometer 34. −15 volts and +15 volts, respectively, are applied to opposite ends of the potentiometer 34 through trimming potentiometers 38 and 39 provided at the ends of the potentiometer 34. The trimming potentiometers 38 and 39 provide for calibration of the range and the end points for each positional output readout. One turn 0.25% linearity, 0.095% resolution potentiometers 34 are utilized on the beam collimator jaws, and position indicators. Ten turn 0.1% linearity, 0.019% resolution potentiometers 34 are provided for each of the other analog positional readouts.

Each of the motorized control motions of the radiation machine 1 is driven by a shunt-wound dc motor 40 operated by an SCR controller 41. With exception of the gantry rotation controller, each controller is open-loop providing full output in response to a 6-volt dc signal, decreasing to 0 output at 0.5 volts dc (±0.5 dead band volts). The gantry speed control is closed loop, speed regulated, full speed output in response to a 12-volt dc input, again with ±0.5 dead band volts. The turntable drive is equipped with a brake which is engaged when the input voltage of the motor controller is zero. The couch longitudinal and lateral motions have switch actuated electric clutches engaging their respective drives.

Control of each motion of the radiation therapy machine 1 is obtained by direct digital control. Positions of each of the eight analog motions are sampled, by sampling the output of each potentiometer 34, every 50 milliseconds, 10 microseconds required for each sample. Sampling is controlled by the central processor 23 and is effected through the interface 21 to the positional control circuits of Fig. 2 coupled to the drive 35 for each of the driven elements of the radiation therapy machine 1. The driven motions are sufficiently fast so as to alter their feedback from zero to full scale in 15 seconds. Assuming a 12-bit plus sign analog-to-digital converter output will vary a maximum of one least-significant bit in 3.6 milliseconds, allowing observation of at most four least-significant bit changes at every reading.

Each patient has in his file a digital tape cassette. For treatment of a patient, his cassette is loaded into the tape unit 28 and a command from the keyboard terminal 29 causes the tape to be read into the central processor 23 and stored in the memory 22 of the computer 18. The information transferred from the cassette to the memory 22 of the computer 18 includes the patients identification number, his name, the diagnosis of his condition, the portal definition of eight separate radiation treatment portals, each including an identification number 1—8 and a definition of the quantities, G, S, X, Y, Z, H, L, T, and dose for each of the defined portals, whether the individual treatment will involve arc therapy, and if so the start and stop gantry angles G, and the rads per degree, and information as to which, if any wedge is to be employed and whether blocks are to be employed. Wedges serve to shape the intensity of the radiation beam, and blocks serve to protect certain portions of the patient being treated for radiation emanating from the beam. In addition, information stored in the memory 22 from the patient's cassette, includes a sequence of how the portal definitions are to be administered, i.e., the treatment plan, the monitored cumulative dose per portal, and the total cumulative dose for the patient.

Once this information has been stored in the computer 18, the keyboard terminal 29 is actuated for displaying desired information from the memory 22 on the display of the keyboard terminal 29. On a proper command from the keyboard terminal 29, the central processor 23 causes to be displayed, from the memory 22, on the cathode ray tube display 29, the next treatment to be given. For example, a certain radiation portal is defined on the visual alphanumeric CRT display, with the prescribed set points for the quantities of G, S, X, Y, Z, H, L, T, etc. Opposite the prescribed values for the aforementioned quantities, which define the treatment to be given, is displayed the corresponding present position of each of the settings of the radiation therapy machine 1. Positional values are obtained from the output of the eight positional circuits of the type shown in Fig. 2 as converted to digital form via the analog-to-digital converters 24 and as sent to the display tube of the keyboard terminal 29, from the central processor 23. In addition to the eight channels employed for positional monitoring, two others of the 16 available channels are used: one other channel is used for monitoring dose rate during exposure of the patient to the radiation, and another channel is used for monitoring the rads-per-degree setting before treatment. Upon depressing the proper command button on the machine control pendant 10, the central processor 23 causes the actual positional signal to be monitored and to be compared with the prescribed positional signal to derive error signals which are fed to the controllers for causing the radiation therapy machine 1 to take the positions defined by the treatment plan being executed.

The core memory 22 has stored therein the permissible ranges of values for the various

adjustable parameters of the radiation therapy machine 1. More particularly, the permissible values stored in the memory are as follows: gantry angle, G, 0 to 359°; turntable angle, S, −90 to +90°; couch X direction travel, X, −856 to +544 millimeters; couch Z direction travel, Z, −20 millimeters to +560 millimeters; radiation head angle, H, −90 to +90°; X-ray beam field length, L, at 80 centimeters from the source, 0 to +320 millimeters; beam radiation field width, T, at 80 centimeters from the source, 0 to +320 millimeters. Also stored in the memory of the computer area: a range of permissible radiation dose times of 0 to 9.9 minutes; dose range of 0 to 999 rads; permissible wedge numbers 0 to 7; gantry stop angle, between 1 and 359°, for arc therapy; and rads per degree for arc therapy, between 0.50 and 5.00.

An anti-collision program, described below in connection with Figure 3, is stored in the memory 22 and the central processor, in conformance with the program, continually checks for the possibility of a collision between the gantry 8 and the couch 2. If imminent collision is determined, an anti-collision subroutine is executed to avert the collision. The radiation machine is positioned in accordance with the predetermined prescribed plan. The geometric set points can be achieved in less than 30 seconds because all of the geometric motions of the radiation machine are obtained simultaneously.

As each of the geometric parameters achieves its set point, the set point value is displayed on the cathode ray tube opposite the corresponding prescribed value for the treatment plan being executed. Thus, all the set point values for the quantities G, S, X, Y, Z, H, L and T are achieved automatically and presented automatically. The planned values for dose time, rads per degree, stop angle, wedge and blocks are displayed but these adjustments are made manually from the machine console 27. Each of the manual adjustments from the machine console 27 has a BCD positional output signal generator of conventional design coupled thereto in the conventional manner. As the manually adjustable parameters are set, the corresponding positional value is fed into the computer 18 and presented on the display adjacent the planned value. Each wedge and block is separately coded with electrical connections and electrical connections are made to these coded connections for feeding an input signal to the computer 18 corresponding to the particular wedge or block employed. Thus wedge and block information is also fed to the computer and presented on the display 29.

The computer 18 is programmed to compare the prescribed value for all of the aforementioned geometric and other machine parameters against the set point values achieved for each of the adjustable parameters. If all of the prescribed values do not conform to the set point values, the computer 18 generates an interlock output signal which is fed via the machine interface 21 to actuate a relay 45 which opens a circuit in the machine console 27 and prevents energization of the radiation "ON" button 46 in the machine console 27 such that the beam of radiation cannot be turned onto the patient until all of the actual set point values for the variable parameters of the radiation machine conform to the prescribed values. This greatly reduces the probability of the operator making a mistake and delivering a dose of radiation to the patient which is not called for by the prescribed treatment plan. Tolerances in the mechanical settings can be built into the system to compensate for uncertainties in patient positioning on the treatment couch 2.

The radiation head portion 12 of the radiation therapy machine 1 includes a dosimeter for monitoring the dose of radiation actually administered to the patient. The output from the dosimeter is continually monitored by the computer 18 throughout the treatment. In particular, Fig. 1 shows the machine console 27, which includes the dosimeter electronic circuitry, connected through the machine interface 21 to the analog-to-digital converters 24, and thence to the central processor 23. The measured radiation dose per treatment is stored in the memory 22 of the computer and displayed on the CRT/terminal display 29. In addition, the computer updates the patient treatment plan status information stored in the memory 22 by updating the portal status portion of the treatment plan to include the cumulative total of radiation dose administered through the particular portal just administered and the total dose administered to the patient. The status information is also updated to include which treatments in the sequence of treatments has been administered and which numbered treatment is to be administered next.

The treatment plan portion of the patient's treatment plan information stored in the memory 22 is also updated by the computer by entering a mark such as an asterisk under the number of the portal definition just administered in the sequence of portal numbers which defines the treatment plan sequence.

After the treatment is terminated an interlock signal goes to the computer 18 from the radiation machine 1. This interlock signal prevents the computer from performing any functions other than printing out the updated portal definition information for the portal just administered. The print out is on the teletype 33. The print out includes the complete portal definition of prescribed and present positions of the elements, etc., together with present date, time, cumulative dose for this

portal and the grand total of dose administered to the patient.

After the print out, the operator types the command END at the keyboard terminal which commands to computer 18 to readout all the updated treatment plan information, portal definition information, etc., relating to this patient from the memory 22 back into the individual patient's tape cassette via the tape deck unit 28.

Any detail of the prescribed overall radiation treatment plan or any one of the prescribed parameters of an individual portal descriptions can be easily changed during the course of treatments. The operator pushes an EDIT button on the CRT keyboard terminal 29 and types in the appropriate change at the keyboard. Two levels of edit capability are incorporated. Certain major changes, such as overall treatment plan, can only be initiated by supervisory personnel with a special access key which serves to complete an interlock circuit in an interface between the CRT/keyboard terminal 29 and the central processor 23. If the therapist desires periodic examination before certain treatment can be administered to the patient, he can require that some one of supervisory rank be present at a given treatment by typing in an appropriate legend in the overall treatment plan.

Any proposed new machine parameter for a change in a treatment plan or portal definition is compared by the computer 18 against the respective permissible ranges for that parameter stored in the memory 22. If the proposed value of the parameter is within the permissible range the change is entered and the treatment plan or portal definition stored in the memory 22 is thus edited.

If the proposed change in parameter is not within the permissible range of values, an error message is displayed on the CRT display 29 and the proposed parameter change is not entered.

The computer assisted radiation machine 1 also includes a simulator mode of operation. In the simulator mode the radiation therapy machine is manually controlled by the operator from the pendant 10 to position the geometric machine parameters for a certain treatment to be administered. The final settings of the machine are monitored by the respective positional output signals and define portions of a complete portal definition. Upon a command the operator causes the computer 18 to transfer the manually set machine parameters into the memory 22 to establish a portal definition in a treatment plan of information stored for that patient in the memory 22. Subsequently this portal definition is completed by the operator and becomes a part of the patient treatment plan to be transferred to his cassette in the manner as previously described above.

When starting, each position is read, compared with its desired set point, and voltage applied to its controller in an ascending linear manner to full scale in order to provide "soft" acceleration and eliminate excessive current surge through upstream circuit breakers. The desired starting periods are determinated empirically, suitable values include 500 milliseconds for gantry rotation, 200 milliseconds for couch elevator motion, and 100 milliseconds for all other motions.

An anti-collision program is stored in the memory 22 and the central processor 23 continually checks for the possibility of a collision between the gantry 8 and the couch 2 in a manner more fully disclosed below. Each controller has full voltage applied until either impending collision is detected or the respective movable element approaches its desired set point. As each desired set point is reached, the corresponding control voltage is reduced in a linear manner inside a proportional band until the indicated position is inside a tolerance band, typically 0.1% of full scale, at which time the control voltage is set to zero. Once again, values for proportional and tolerance bands are established empirically. When each motion has been brought to a stop at its respective set point, control returns to the display-input-output routines.

The anti-collision program examines all possible collision modes for the current combination of radiation therapy machine parameters. If safety envelopes around proximate members are invaded, all motions are stopped. The final increment above the actual physical dimensions for defining the safety envelope has been selected at approximately 1″. When imminent collision is detected and motions stopped, the program causes the four motional prime candidates for collision; namely, gantry rotation, couch rotation, couch lateral displacement, and couch elevation, to be moved briefly, i.e., for 5 seconds, toward their neutral positions. Then this motion is stopped, another attempt is made at the desired set points by causing the various motions to resume tracking toward their desired set points. If this new attempt is unsuccessful, all motion is stopped and the sequence repeats for a certain predetermined number, such as five times. If after five attempts collision is still imminent, all motions are stopped with finality and an error message is displayed on the cathode ray tube of the keyboard terminal 29.

Referring now to Fig. 3 and the four sheets of drawings included as a part thereof, there is shown the simplified flow chart for the collision avoidance program, showing the types of possible collisions, how their probability is determined, and the sequence of calculations made to determine impending collision.

In the program flow chart conventional nomenclature has been employed for designat-

ing the functions. More particularly, a diamond shaped box means a simple decision function, a rectangular box means a calculation. The numbers in parenthesis associated with each box is the algorithm employed in the calculation and is found in the table of algorithms below. The flow chart reads from top to bottom and from left to right. The home plate-shaped boxes indicate that the flow diagram continues on another page and the other page is entered at the circular box with the same number employed in the home plate box. If the flow diagram branch terminates with a circular box with a number, the program continues on that same page above at the position marked with a circular box with the same number. The inverted trapezoid-shaped box indicates that a message is displayed on the CRT display 29, or printed, conforming to that message marked inside the box.

The control algorithm for automation of the radiation therapy machine 1 is designed to provide rapid simultaneous motion of the eight mechanical adjustments of the radiation therapy machine to prescribed set points as provided in the treatment plan stored in the memory. Potential collision is monitored, prevented, avoided if possible, and if otherwise inevitable due to erroneous set points all motions are stopped and an error message is displayed. Each motion is sequentially "soft started" in order to avoid overloading the control circuits.

For the purposes of the anti-collision program the couch is defined to include a patient. It is assumed the patient occupies a volume of space above the table top 45.7 cm wide, 203.2 cm long, 25 cm high, flat ends, and with curved sides tangent to the side edge of the table top 3 and curving to the upper side of the patient zone with a radius of curvature of 40 cm.

The control algorithm is divided into four sections: (1) the control logic tree, (2) collision testing sub-routines, (3) motion control sub-routine, and (4) collision avoidance sub-routine.

Table of Algorithms
(Dimensionless numbers are in millimeters)

(1.1.1) The main branch in the logic occurs based on whether the patient couch is aligned with the gantry axis

$$(\text{angle } S \leqq \frac{1^\circ}{2}).$$

If so, and couch height (Z) is less than or equal to 84 mm, the most likely collision is between the collimator housing and the edge of the couch top which can occur if:

$$(Z+10)^2+[229+|Y|]^2>R_c^2$$

where Y represents couch lateral translation and R_c is the radius to the collimator housing from isocenter in millimeters. 10 is the thickness of the couch table top and 229 is half the width of the couch. If collision is impossible, the motion control sub-routine (6.1.1) is called.

(1.3.1) If S=0 but Z is between 84 and 278 mm, the most likely collision is between the collimator housing and the edge of the couch rail, possible if:

$$(Z+61)^2+[213+|Y|]^2>R_c^2$$

If collision is not possible, the motions control sub-routine (6.1.1) is called. 61 is the thickness of the rail and table and 213 is half the distance between the outer edges of the rails.

(1.4.1) If rail/collimator collision is possible, Z is greater than 242 mm, and G is between 90° and 270°, the possibility of collision between the couch rails and the beamstopper is examined:

$$(Z+61)^2+[213+|Y|]^2>R_b^2$$

where R_b is the radius to the beamstopper from isocenter in millimeters.

(2.1.2) Couch rail edge and collimator housing:

$$[(|Y|+213)\times|\sec(s)|+254|\tan(s)|]^2>R_c^2-(Z+61)^2$$

(2.1.3) Couch top edge and collimator housing:

$$[(|Y|+213)\times|\sec(s)|+254|\tan(s)|]^2>R_c^2-(Z+10)^2$$

(2.1.4) Couch rail edge and beamstopper:

$$[(|Y|+213)\times|\sec(s)|+470|\tan(s)|]^2>R_b^2-(Z+61)^2$$

(2.1.5) Couch top edge and beamstopper:

$$[(|Y|+229)\times|\sec(s)|+470|\tan(s)|]^2>R_b^2-(Z+10)^2$$

(2.1.6) Couch rail corner and collimator housing:

$$[(|Y|+213)\times|\cos (s)|+X|\sin (s)|]^2>R_c^2-(Z+61)^2$$

(2.1.7) Couch top corner and collimator housing:

$$[(|Y|+229)\times|\cos (s)|+X|\sin (s)|]^2>R_c^2-(Z+10)^2$$

(2.2.2) Couch rail corner and beam stopper:

$$[(|Y|+213)\times|\cos(s)|+X|\sin (s)|]^2>R_b^2-(Z+61)^2$$

(2.2.3) Couch top corner and beam stopper:

$$[(|Y|+229)\times|\cos (s)|+X|\sin (s)|]^2>R_b^2-(Z-10)^2$$

(2.3.1) Beam stopper and elevator side:

$$R_b (1-\Delta)-280|\sec (s)|\ |\csc (G)|-R_{b1} (1+\Delta)\ [|\tan (s)|\cos (A)+|\cos (G)|\sin (A)]\ |\csc (G)|<0$$

where:

$A=\arc \tan [|\cot (s)|\ |\cos (G)|]$, Δ is a cushion factor such that an impending collision between the beam stopper and the elevator side is sensed, and a corrective signal is generated, if the distance between the beam stopper and the elevator side becomes equal to or less than one inch (25.4 mm). Thus $\Delta R_b=25.4$. 280 is half the elevator width, R_{b1} is the radius of the beam stopper in mm and if $S>17°$; and

$$R_b (1-\Delta)\ |\sin (G)|-R_{b1} (1+\Delta)\ |\sin (B)|-585|\sin (s)|<0$$

where

$$B= \arc \tan [\tan (A)|\cos (G)|] \text{ and } A=\frac{\arc \cos [585|\cos (s)|]}{R_{b1} (1+\Delta)}$$

if

$$6°<s\leq17°$$

(2.3.2) Beam stopper and elevator end:

$$R_e|\csc (s)|-794|\sin (G)|-R_{b2} (1+\Delta)\ [\cos (A)|\cot (s)|+\sin (A)|\cos (G)|<0$$

where

$A=\arc \tan [|\tan (s)|\ |\cos (G)|]$ and R_e is the radius from turntable axis to the elevator end, and R_{b2} is the radius of the farside of the beamstopper from beam axis 13.

(2.4.1) If G is between 270° and 90°, collimator housing and couch rail:

$$R_c|\cos (G)|-R_{c1}\ (1+\Delta)\ |\sin (G)|<Z+61$$

where

R_{c1} is the radius of the collimator housing

(2.4.2) Beamstopper and patient:

$$R_{b1}\ (1+\Delta)|\sin (G)|-R_b\ (1-\Delta)|\cos (G)|>Z-250$$

where

250 is the assumed thickness of the patient

(2.4.3) If G is between 90° and 270°, collimator housing and patient:

$$R_{c1}\ (1+\Delta)|\sin (G)|+R_c\ (1-\Delta)|\cos (G)|>Z-250$$

(2.4.4) Beamstopper and couch rail:

$$R_b\ (1-\Delta)|\cos\ (G)|-R_{b1}\ (1+\Delta)|\sin\ (G)|<Z+61$$

(3.2.1) Gantry corner and elevator side:

$$750|\sin\ (G)|-407|\cos\ (G)|\ |\cos\ (s)|-318|\sin\ (s)|-280<0$$

(3.2.2) Gantry corner and elevator end:

$$[514|\sec\ (s)|-318]|\cot\ (s)|-985|\sin\ (G)|-407|\cos\ (G)|<0$$

(4.2.1) Collimator housing and elevator corner:

Collision imminent if S>36° and G is between 80° and 90° or S<−36° and G is between 270° and 280°. If this test indicates impending collision and the arc flag is not set, the collision avoidance sub-routine is called. If the arc flag is set and collision is indicated, the program exits with an error message display. If no collision is possible, the motion control sub-routine is called.

(5.1.1) Beamstopper vs. float table edge:

$$[(|Y|+280)|\sec\ (s)|+470|\tan\ (s)|]^2>R_b^2-(Z+210)^2$$

(5.1.2) Beamstopper vs. float table sides:

$$R_b\ (1-\Delta)-(280+|Y|)\ |\sec\ (s)|\ |\csc\ (G)|R_{b1}\ (1+\Delta|\tan\ (s)|\cos\ (A)+ |\cos\ (G)|\sin\ (A)|\csc\ (G)|<0$$

where

$$A=\text{arc}\ \tan|\cot\ (s)|\ |\cos\ (s)|$$

(6.1.1) Motion control sub-routine
Each of the eight mechanical positions is monitored and compared against its respective setpoint. Each motion is assigned a tolerance band and a proportional control band. For each motion, if the error between the setpoint and measured position exceeds the tolerance band, voltage is applied to direct the motion toward the setpoint. If no control voltage is currently being applied, a timed voltage increase to maximum is applied to provide "soft" acceleration, thereby reducing peak current to within the limits of the control circuitry. Proximity to each set point is continually monitored, and when a motion moves within the proportional control band, control voltage is reduced linearly to zero within the tolerance band.

(7.1.1) Collision avoidance sub-routine first stops all mechanical motions and resets a counter. For a timed interval, the turntable, gantry and couch X and Z motions are driven toward their respective zero positions. Another attempt is then made to achieve the intended setup. If, after a preset number of trials imminent collision remains indicated, all motions are stopped and an error message displayed.

A closely related radiation apparatus is described and claimed in copending U.K. Patent Application No. 52585/71 (Serial No. 1,362,678).

WHAT WE CLAIM IS:—

1. A radiation therapy apparatus comprising couch means for supporting a patient to receive radiation, radiation source means for applying radiation to the patient, means for supporting and moving said radiation source means around said couch means, means for storing information defining geometric and radiation dose parameters of the radiation machine for defining a prescribed radiation treatment to be administered to the patient, means for reading out of said storage means and displaying to an operator the geometric and dose parameters defining the prescribed plan of radiation treatment, means for deriving an output representative of the dose of radiation actually administered to the patient from said source means in carrying out the defined plan of treatment, means for editing and updating said storage means with the derived dose output by adding the derived dose output to the cumulative total of previously derived dose outputs, if any, administered to the certain patient and stored in said storage means, to obtain an updated cumulative total radiation dose output in said storage means.

2. The apparatus of claim 1 wherein said means for displaying and reading out of said storage means the parameters of a prescribed plan of treatment includes, means for reading out the edited and updated cumulative total radiation dose output from said edited and updated storage means.

3. The apparatus of claim 1 wherein said storage means and said editing and updating means includes, a programmed general purpose computer.

4. The apparatus of claim 3 wherein said readout and display means includes, cathode ray tube terminal means interactively coupled to said general purpose computer means.

5. The apparatus of claim 3 wherein said readout and display means includes, teletype terminal means interactively coupled to said programmed general purpose computer means for printing out the edited and updated treatment plan parameter stored in said storage means.

6. The apparatus of claim 1 wherein said means for deriving an output representative of the dose of radiation actually administered to the patient includes, dosimeter means disposed in the beam of radiation administered to the patient.

7. The apparatus of claim 1 including, programmed general purpose computer means having a memory portion, and wherein said storage means for storing the geometric and dose parameter information defining a prescribed radiation treatment plan includes said memory of said computer means, and including second information storage means for storing geometric and dose parameter information defining a prescribed radiation treatment plan for a given patient, means for reading the treatment plan information stored in said second storage means into said memory portion of said computer means, means for recording information in said second information storage means, and said computer means being programmed to read the edited and updated treatment plan information from said memory portion of said computer to said recording means for recording the updated treatment plan information in said second information storage means.

8. The apparatus of claim 7 wherein said second storage means includes, an information storage tape medium.

9. The apparatus of claim 1 wherein, said storage means also includes means for storing information defining permissible range of values of treatment plan parameters for radiation treatment plans to be administered to the patient, means for comparing a proposed radiation treatment plan parameter against the respective parameter of the range of permissible values to derive an interlock output if the value of the proposed machine parameter is outside the respective range of permissible parameter values, and means responsive to the interlock output to prevent transfer of the out-of-range proposed machine parameter into the prescribed set of treatment plan parameters stored in said storage means.

For the Applicant(s):
A. POOLE & CO.,
Chartered Patent Agents,
19, Devonshire Street,
London, W1N 2BJ.

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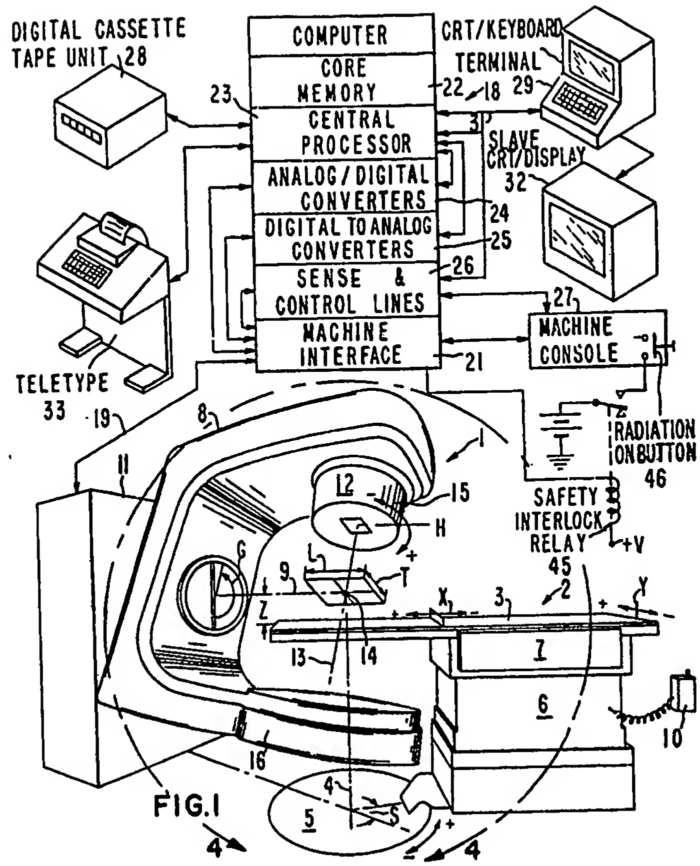

DIGITAL CASSETTE TAPE UNIT 28
COMPUTER
CORE MEMORY
CENTRAL PROCESSOR
ANALOG/DIGITAL CONVERTERS
DIGITAL TO ANALOG CONVERTERS
SENSE & CONTROL LINES
MACHINE INTERFACE
CRT/KEYBOARD TERMINAL 29
SLAVE CRT/DISPLAY 32
MACHINE CONSOLE
RADIATION ON BUTTON 46
SAFETY INTERLOCK RELAY 45
+V
TELETYPE 33
23
22
18
31
24
25
26
27
21
19
8
11
12
15
H
G
L
9
T
X
Y
Z
13
14
7
6
10
16
5
S
4

FIG.1

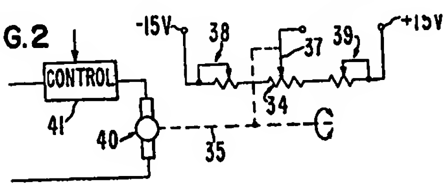
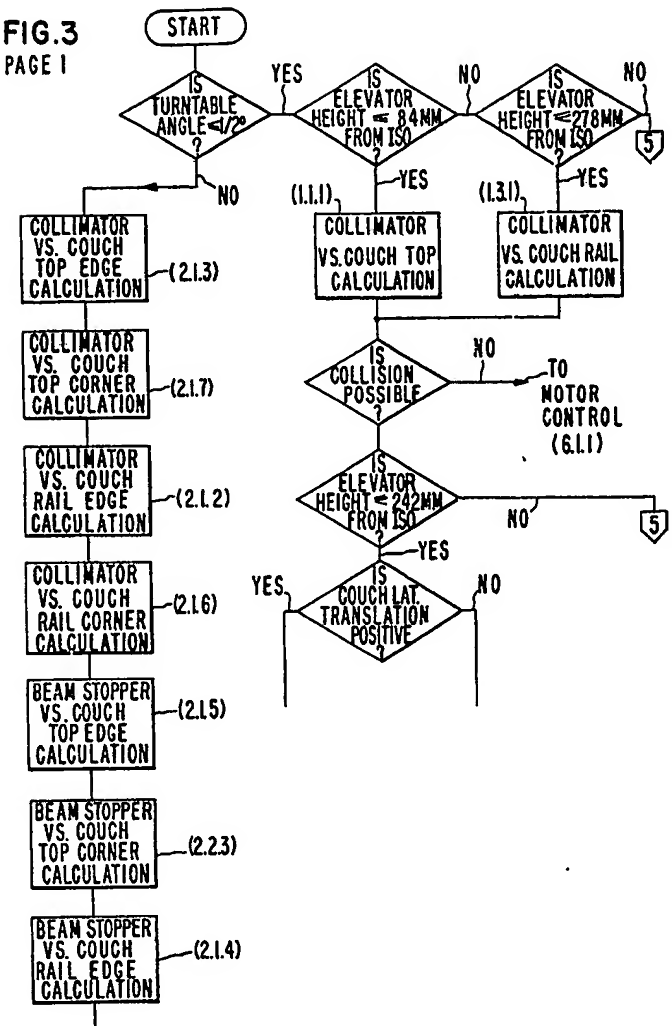

CONTROL
41
40
35
-15V
38
37
39
+15V
34
G

FIG.2

FIG.3
PAGE 1


START
IS TURNTABLE ANGLE ≤1/2° ?
YES
NO
IS ELEVATOR HEIGHT ≤ 84MM FROM ISO ?
NO
YES
IS ELEVATOR HEIGHT ≤ 278MM FROM ISO ?
NO
YES
5
(1.1.1)
COLLIMATOR VS. COUCH TOP CALCULATION
(1.3.1)
COLLIMATOR VS. COUCH RAIL CALCULATION
COLLIMATOR VS. COUCH TOP EDGE CALCULATION
(2.1.3)
COLLIMATOR VS. COUCH TOP CORNER CALCULATION
(2.1.7)
COLLIMATOR VS. COUCH RAIL EDGE CALCULATION
(2.1.2)
COLLIMATOR VS. COUCH RAIL CORNER CALCULATION
(2.1.6)
BEAM STOPPER VS. COUCH TOP EDGE CALCULATION
(2.1.5)
BEAM STOPPER VS. COUCH TOP CORNER CALCULATION
(2.2.3)
BEAM STOPPER VS. COUCH RAIL EDGE CALCULATION
(2.1.4)
IS COLLISION POSSIBLE ?
NO
TO MOTOR CONTROL (6.1.1)
IS ELEVATOR HEIGHT ≤ 242MM FROM ISO ?
NO
5
YES
IS COUCH LAT. TRANSLATION POSITIVE ?
YES
NO

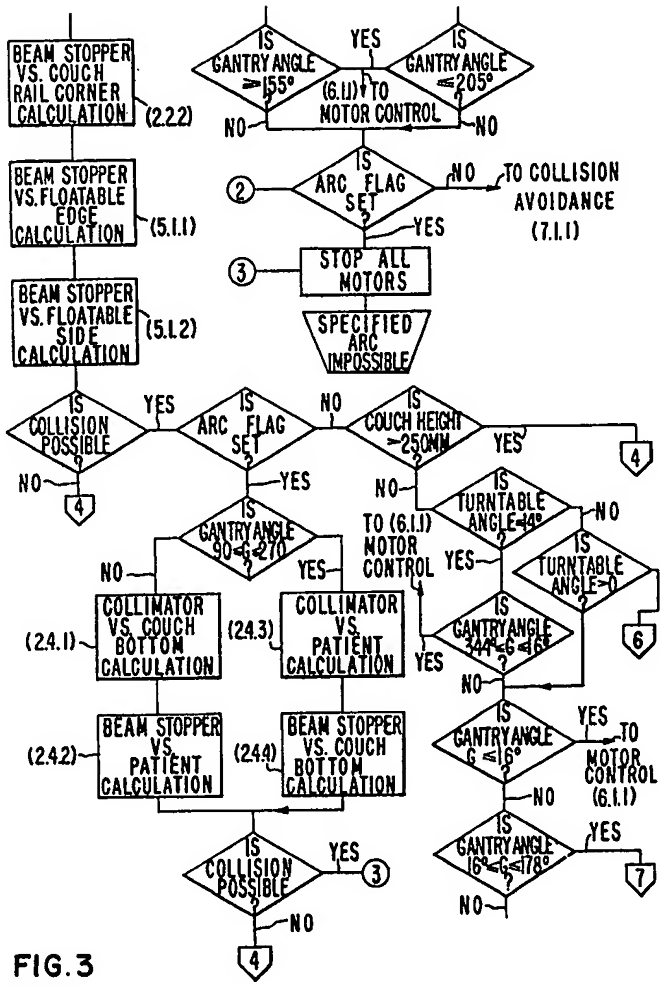
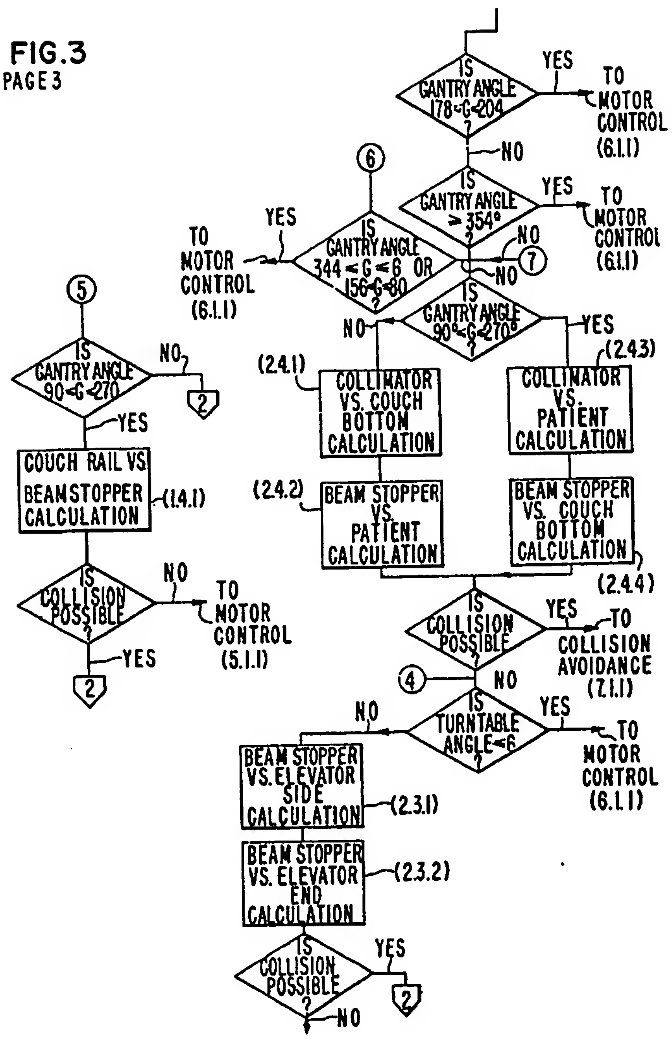

BEAM STOPPER VS. COUCH RAIL CORNER CALCULATION
(2.2.2)
IS GANTRY ANGLE ≥155° ?
YES
IS GANTRY ANGLE ≤205° ?
(6.1.1) TO MOTOR CONTROL
NO
NO
BEAM STOPPER VS. FLOATABLE EDGE CALCULATION
(5.1.1)
2
IS ARC FLAG SET ?
NO
TO COLLISION AVOIDANCE (7.1.1)
YES
3
STOP ALL MOTORS
BEAM STOPPER VS. FLOATABLE SIDE CALCULATION
(5.1.2)
SPECIFIED ARC IMPOSSIBLE
IS COLLISION POSSIBLE ?
YES
IS ARC FLAG SET ?
NO
IS COUCH HEIGHT >250MM ?
YES
4
NO
4
YES
NO
IS TURNTABLE ANGLE ≤4° ?
NO
IS GANTRY ANGLE 90≤G≤270 ?
TO (6.1.1) MOTOR CONTROL
YES
IS TURNTABLE ANGLE >0 ?
NO
YES
COLLIMATOR VS. COUCH BOTTOM CALCULATION
(2.4.1)
(2.4.3)
COLLIMATOR VS. PATIENT CALCULATION
IS GANTRY ANGLE 344°≤G≤16° ?
YES
6
NO
IS GANTRY ANGLE G ≤16° ?
YES
TO MOTOR CONTROL (6.1.1)
BEAM STOPPER VS. PATIENT CALCULATION
(2.4.2)
(2.4.4)
BEAM STOPPER VS. COUCH BOTTOM CALCULATION
NO
IS GANTRY ANGLE 16°≤G≤178° ?
YES
7
NO
IS COLLISION POSSIBLE ?
YES
3
NO
4

FIG. 3
PAGE 2

FIG.3
PAGE 3


IS GANTRY ANGLE 178<G<204 ?
YES
TO MOTOR CONTROL (6.1.1)
NO
IS GANTRY ANGLE ≥354° ?
YES
TO MOTOR CONTROL (6.1.1)
NO
7
6
IS GANTRY ANGLE 344≤G≤6 OR 156<G<80 ?
YES
TO MOTOR CONTROL (6.1.1)
NO
IS GANTRY ANGLE 90°<G<270° ?
NO
YES
(2.4.1)
COLLIMATOR VS. COUCH BOTTOM CALCULATION
(2.4.3)
COLLIMATOR VS. PATIENT CALCULATION
(2.4.2)
BEAM STOPPER VS. PATIENT CALCULATION
BEAM STOPPER VS. COUCH BOTTOM CALCULATION
(2.4.4)
IS COLLISION POSSIBLE ?
YES
TO COLLISION AVOIDANCE (7.1.1)
NO
4
IS TURNTABLE ANGLE<6 ?
YES
TO MOTOR CONTROL (6.1.1)
NO
BEAM STOPPER VS. ELEVATOR SIDE CALCULATION
(2.3.1)
BEAM STOPPER VS. ELEVATOR END CALCULATION
(2.3.2)
IS COLLISION POSSIBLE ?
YES
2
NO
5
IS GANTRY ANGLE 90<G<270
NO
2
YES
COUCH RAIL VS BEAMSTOPPER CALCULATION
(1.4.1)
IS COLLISION POSSIBLE ?
NO
TO MOTOR CONTROL (5.1.1)
YES
2

1362679 COMPLETE SPECIFICATION

6 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 6

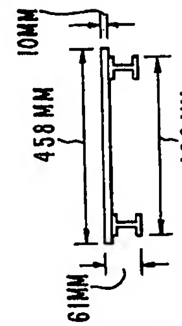


FIG.5

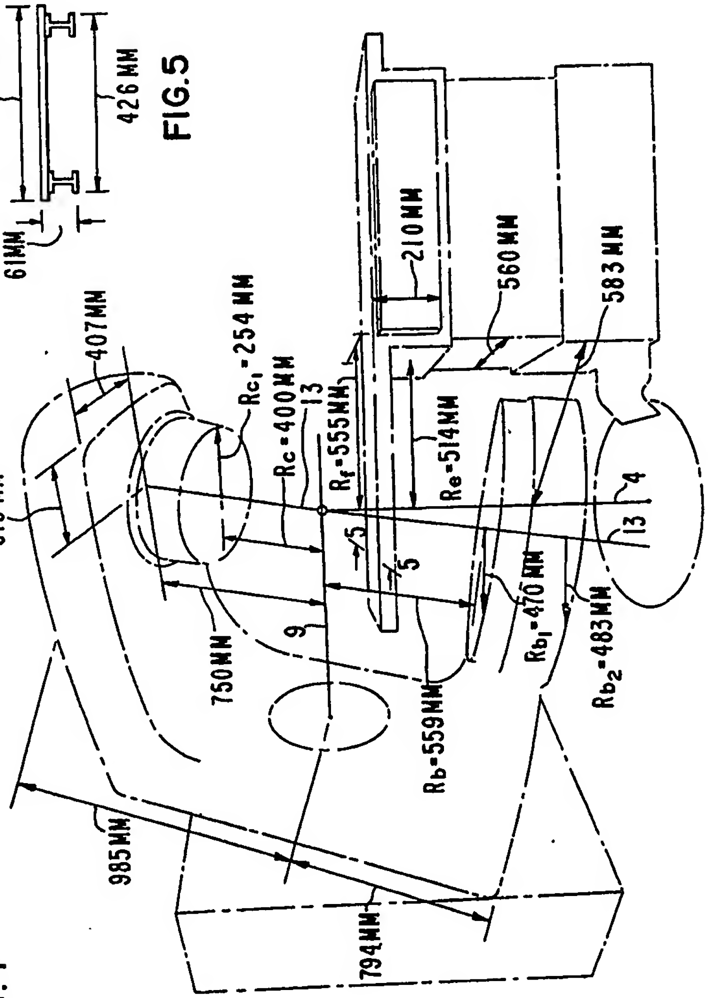


FIG.4